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Evaluating the environmental impact of debit card payments[*]

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Abstract

Purpose: Consumers in the Netherlands made more than 3.2 billion debit card transactions at points-of-sale in 2015, corresponding to over half of all point-of-sale payments in that year. This study provides insights into the environmental impact of debit card transactions based on a life cycle assessment (LCA). In addition, it identifies several areas within the debit card payment chain where the environmental impact can be reduced.
Methods: The debit card payment system can be divided into three subsystems: debit cards, payment terminals, and datacentres used for transaction processing. Input data for all elements within each subsystem (manufacturing, transport, energy use, and disposal) were retrieved from interviews and literature study. Seven key companies and authorities within the debit card system such as the Dutch Payments Association, two banks, two datacentres, one payment terminal producer and a recycling company contributed data. The analysis is conducted using SimaPro, the Ecoinvent 3.0 database and the ReCiPe endpoint (H) impact assessment method.
Results and discussion: One Dutch debit card transaction in 2015 is estimated to have an absolute environmental impact of 470 µPt. Within the process chain of a debit card transaction, the relative environmental impact of payment terminals is dominant, contributing 75% of the total impact. Terminal materials (37%) and terminal energy use (27%) are the largest contributors to this share, while the remaining impact comprises datacentre (11%) and debit card (15%) subsystems. For datacentres, this impact mainly stems from their energy use. Finally, scenario analyses show that a significant decrease (44%) in the environmental impact of the entire debit card payment system could be achieved by stimulating the use of renewable energy in payment terminals and datacentres, reducing the standby time of payment terminals, and by increasing the lifetimes of debit cards.
Conclusions: For the first time, the environmental consequences of electronic card payment systems are evaluated. The total environmental impact of debit card transactions in the Netherlands is relatively modest compared to the impact of cash payments, which are the closest substitute of debit card payments at the point-of-sale. Scenario analysis indicates that the environmental impact can be reduced by 44%.

Keywords: Datacentre, Debit card payment system, Debit card, Environmental impact, LCA, Payment terminal.
JEL classifications: E42, Q50.

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1. Introduction

Although the impact of a single payment may be negligible, the enormous number of payments worldwide gives reason to believe that payment systems may have a substantial environmental impact. In 2014, for example, there were around 400 billion global non-cash transactions (Capgemini/BNP Paribas, 2016). Little is known, however, about the environmental impact of the payments that are made.

In the Netherlands, consumers made 3.23 billion debit card transactions at the point-of-sale (POS) in 2015 with a total value of EUR 92.5 billion. In that year the number of debit card transactions at the POS surpassed the number of cash transactions for the first time; the Dutch made 3.19 billion cash payments representing EUR 38 billion in value (DNB/DPA, 2016). Debit card usage is expected to increase further in the coming years at the expense of cash payments (MOB, 2016). This is a worldwide trend. In many countries, consumers increasingly use card payments at the point-of-sale (POS), see e.g. Bolt, Jonker and Plooij (2016). Credit cards are rarely used in the Netherlands. In total Dutch consumers made 45 million credit card payments, of which 2/3 at the POS and 1/3 for online payments (DNB, 2017). Compared to POS payments, payments for online purchases represent a relatively small, but increasing share of consumer expenditures. Between 2014 and 2015 the number of online payments increased by 17% to 142 million payments, and the total value of these payments rose by 16% to EUR 16.1 billion (Thuiswinkel.org, 2016), whereas the total number and value of POS payments increased slightly, i.e. by 1%. The much sharper rise in online purchases than in POS payments indicates that online purchases are gradually replacing POS purchases. In 2015, Dutch consumers mainly used the online e-commerce payment solution iDEAL for their online purchases, which initiates online credit transfers (56% of all online payments), followed by credit card (12%), direct debit (6%), credit transfers initiated by consumers themselves (5%) and Paypal (5%) (DPA, 2016). For other remote payments, such as for recurrent payments or bills, the Dutch mainly use direct debit payments or credit transfers (DNB, 2017). However, the environmental impact of a debit card transaction, or any other mainstream electronic payment mechanism, has not yet been investigated. The environmental impact of increasing debit card usage is therefore unknown. This analysis attempts to obtain such information, focusing on the case of the Netherlands. It aims to both provide insights into the overall environmental impact of debit card payments, as well as to identify areas of relative environmental concern within all stages of the process of conducting a debit card transaction. Furthermore, it examines the global warming potential (GPW) of the Dutch debit card payment system, as the Dutch financial sector aims to contribute to the reduction of CO_2-emissions. Both these goals are met by conducting a life cycle assessment (LCA), using input data from seven key companies and authorities within the Dutch debit card system such as the Dutch Payment Association, banks, transaction processing hosts, payment terminal producers, and a recycling company.

Several studies have been published on the environmental impact of cash payments, see for example Swiss National Bank (2000), European Central Bank (2005), Bank of Canada (2011) and Bank of England (2013). All these studies evaluate the environmental impact of banknotes. Hanegraaf (2017) and Larcin (2017) also take into account the impact of euro coins, next to euro banknotes. With respect to more recent innovations, a number of primarily non peer-reviewed reports on bitcoin payments have appeared. O'Dwyer and Malone (2014) and Hayes (2015) assess the energy footprint of bitcoin mining. Both reports' conclusions indicate a significant and ever-increasing total energy consumption, leading to a high overall environmental impact per bitcoin payment.

2. Methodology

The LCA was performed based on the ISO 14040 standard. The attributional LCA-type was chosen, which enables comparisons between the direct impacts of products, and is used to identify opportunities for reducing direct impacts in different parts of the life cycle (Brander et al., 2009). The impact assessment method ReCiPe (H) was applied and processed with SimaPro software.[5] The results are presented as a 'single score' expressed in Pt. This is a score obtained by weighting the normalised indicator results for the three damage categories (human health, ecosystem quality and resources). Additionally, the IPCC Global Warming Potential (GWP) method is used to calculate the climate

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[5] In SimaPro the following databases were used: Ecoinvent 3.0, CE Generic data, USA Input Output Database and Industry data 2.0.

change impact expressed in CO_2 equivalents. Throughout the research process, the inventory data, system boundaries and methodology have been peer reviewed as recommended by Klöppfer et al. (1996). Significant data gaps are further explained in Section 5 ‘Conclusions and limitations’.

2.1 Goal and scope definition

The goal of this LCA study is to identify, analyse and quantify the environmental impact of a debit card payment, based on the product system for point-of-sale (POS) debit card payments in the Netherlands in 2015. The functional unit used in this LCA is an average point-of-sale (POS) debit card transaction of EUR 28.68 in the Netherlands in 2015 (MOB, 2016). The debit card payment system is, for purposes of clarity, divided into three subsystems: the debit card, used by consumers to initiate a debit card payment at the POS, the payment terminal at the POS, which reads and approves debit card payments, and the datacentres, which process the debit card payments, see Figure 1.

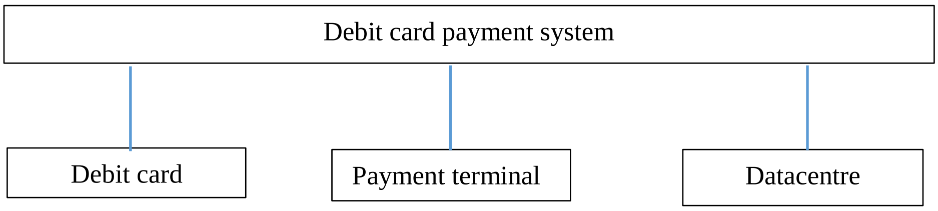

Figure 1. Schematic overview of the debit card payment system.

2.2 Data and assumptions

SimaPro 8.0 software was used to model the system (Pré Consultants, 2015). Most of the secondary data was obtained from the Ecoinvent 3.0. database, while additional secondary data (e.g. the average Dutch energy mix) were mainly retrieved from CE Delft’s ‘generic data’ database (CE Delft, 2015; Afman and Wielders, 2014). Primary data is either received from personal communication with stakeholders responsible for services within the debit card payment system, or from publicly available resources. Recycling is assessed through a sensitivity assessment, in which the lifetime of payment terminals is extended. For incineration, average electrical and thermal efficiencies of Dutch municipal waste incinerators are applied. Seven key companies and authorities within the debit card system such as the Dutch Payments Association, two banks, two datacentres, one payment terminal producer and a recycling company contributed data. They cover a large part of the Dutch debit card market. The next sections provide detailed information of the life cycle inventory and data sources used for modelling, as well as the assumptions and the system boundaries per subsystem. Due to confidentiality reasons detailed information on the identity is withheld.

2.2.1 Debit card

A debit card has more functions besides just being used in POS debit card transactions. It is also used to withdraw cash at ATMs and to initiate and authorize online credit transfers. The debit card's environmental burden should therefore be allocated to each of its uses. Taking into account the number of cash withdrawals (351 million) and online transactions using a debit card (558 million) resulted in 4.135 billion uses of the debit card and an allocation of 78% of the environmental burden of the debit card system in 2015 to the 3.23 billion debit card transactions at the POS (MOB, 2016). This is applied to its production, transportation and disposal.

In 2015, 7.45 million debit cards were produced and assembled for the Dutch market in Southern and Eastern European countries (Personal communication with bank 2, 2016). The most important materials in a debit card are PVC for its body, and copper, for its chip module and NFC reader (Rankl and Effing, 2010). Other components mainly consist of metal conductors. Tables 1 and 2 provide an overview.

After production and assembling, the debit cards are transported to the Netherlands and distributed among cardholders. Transportation is measured by the total amount of tonnekm's by trucks, varying from <5t vans to 10-20t lorries. After an average lifespan of 3.5 years (personal communication with bank 1), the cardholder disposes of the debit card via the general municipal waste, from where it is transported to waste incineration plants. Data on European transportation of debit cards is listed in table A.1 in the appendix.

Table 1. Inventory of debit card body

Material type	Modelled Material	Amount (g)	Source
ID-1 card body: plastics (mostly PVC)	Materials (Polyvinylchloride, suspension polymerised {GLO}|, PET film (production only) E.) Injection moulding	3.486 g	Rankl and Effing, 2010
ID-000 card body (plug-in): plastics (mostly PVC)	Materials (Polyvinylchloride, suspension polymerised {GLO}|, PET film (production only) E.) Injection moulding	0.914 g	Rankl and Effing, 2010
Antenna Inlay for NFC	Copper wires (Copper {GLO}|)	0.1 g	Personal Communication with bank 1, 2016. Weight determined by estimation
Ink: resins and pigments, low amounts. Magnetic strip: iron oxide, inks, and glue, very low amounts. Glue for bonding module to body: epoxy resin, very low amounts.	N/A	0	Rankl and Effing, 2010
Total weight (not including chip):		~4.5 g.	Own calculation

Table 2. Inventory of debit card chip module

Material type	Modelled material in SimaPro	Density (g/mm^3)	Surface & Thickness (mm^2 & mm) [Possehl Electronics, 2010]	Amount (g) (surface* thickness * density)	Source
Nickel	Average metal working process Nickel, 99.5% {GLO}|	0.008908	Bonding side: thickness: 3.5um Surface: 0.71mm * 0.71 mm Contact side: Thickness: 2.0um Surface: 1.42mm*1.42mm	Total: 0.00005164	For density: Stone Foundries, 2016
Copper	Average metal working process Copper {RER}| production, primary |	0.00892	Overall top contact layer: Surface: 12mm width * 8mm length Thickness: 0.08mm thickness 35 um Surface: 1.42mm*1.42mm	Total: 0.069129	For density: Stone Foundries, 2016
Gold	Average metal working process Gold {RoW}| production	0.0193	Bonding side: thickness: 0.3um Surface: 0.71mm * 0.71 mm Contact side : Thickness 0.1um Surface: 1.42mmx1.42mm	Total: 0.0000067	For density: Stone Foundries, 2016
Glass Epoxy	Glass epoxy working process Glass fibre reinforced plastic, polyester resin, hand lay-up {GLO}|	0.0018	thickness 110 um Surface: 0.71mm * 0.71 mm	Total: 0.0000998	For density: Wang et al., 2011
Epoxy Resin	Epoxy resin working process Epoxy resin, liquid {GLO}|	0.0012	thickness 20 um Surface: 0.71mm * 0.71 mm	Total: 0.00012	For density: Wang et al., 2011
Silicon	Microcontroller (10mm^2): silicon with doping elements Silicon, electronics grade {RoW}|			Total: 0.009	Rankl and Effing, 2010

Figure 2 provides a schematic overview of the debit card system's boundaries. All relevant sub processes presented for the debit card system have been taken into account in the inventory analysis or have been estimated if possible (see below). A detailed investigation of the environmental impact of the material input of debit cards is provided. The manufacturing phase has been simplified to include three steps that are considered most relevant for both the debit card body (extrusion of plastic film, thermoforming or lamination, and metal working) as well as the chip (injection moulding, metal working and brazing solder) (Mayes and Markantonakis, 2008). A more precise overview of all manufacturing steps, including e.g. sheet cutting and digital printing, is provided by Ebner (2008). These manufacturing steps are considered to be outside of the scope of this assessment due to their assumed relatively small environmental impact.

Furthermore, the environmental impact of three transportation phases within Europe are taken into consideration. The transportation from the personalization facilities to the customer (consumers) has been simplified by excluding the environmental footprint of the fraction of the Dutch postal system used to distribute the individual cards. The transportation of the cards from the customers to the Dutch municipal waste incinerators has been estimated by assuming an average distance from customer to waste processing plant of 30 kilometres. Furthermore, packaging materials are not taken into account in the three transportation phases.

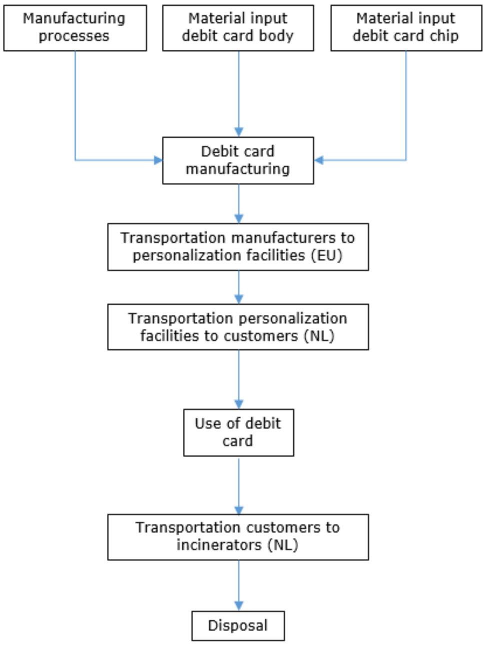

Figure 2. Schematic overview of the debit card system.

For the disposal phase, it is assumed that all debit cards will eventually be disposed of with the general municipal waste, after which they will be incinerated. This assumption is based on the fact that both banks and governmental bodies do not have an active policy regarding the returning and recycling of customers' debit cards after use. This results in debit cards being disposed via regular municipal waste facilities (Personal communication, bank 1, 2016). However, some cards are being recycled. One million cards per three years for all banks together are being incinerated at a specialized facility. This comes down to the incineration of 333 thousand debit cards per year (4.6% of all debit cards).This is mostly because of incorrect orders or mistakes in manufacturing or personalization of the debit cards, prior to usage. The professional incineration of the plastics (PVC) in debit cards generates energy in the form of electricity (0.014MJ per card) and gas (0.016 MJ per card).[6]The total value of the energy recovered from one debit card is 0.030 MJ.

2.2.2 Payment terminals

The number of POS terminals in the Netherlands in 2015 was 326,993 (MOB, 2016). Therefore, the average number of transactions per terminal in 2015 was 9864 (3,225,597 000/326,993) and the average number of debit card transactions per terminal per day was 27.2 (9864/365). In consultation with experts, a 'model' payment terminal was selected to be investigated in further detail. The underlying reason for this decision is the relatively small assumed differences in material- and energy use between different terminals, and the high level of available detailed information on the model chosen. Due to market sensitivity, the specific model and producer cannot be made public. Roughly, a payment terminal consists of the following components: a polycarbonate casing, LCD screen, rubber keypad, lithium battery or power supply, thermal printing paper, and internal electrical components such as the printed circuit board and integrated circuits. Table 3 provides an overview.

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[6] According to Endres & Siebert-Raths (2009) both the electronic and gas incineration of PVC amounts 19 MJ/kg. According to CE Delft the efficiency of electronic incineration amounts 17% and of gas incineration 19%. As each debit card contains 0.0044 kg on PVC, the energy generated through electronic incineration amounts 0.014MJ and through gas incineration 0.016 MJ.

Table 3. Inventory of materials of a ‘model’ terminal.

Material	Weight	Source	Modelled process
Power supply	1 unit per terminal (+/-80 g.)	Estimation (total terminal weight of 308 g., as retrieved from the model datasheet, minus the (estimated) weights of its components.	Power supply unit, for desktop computer {GLO}|
Lithium battery	1 unit per terminal (+/ 30 g.)	model Datasheet	Battery cell, Li-ion {GLO}|
Top case: PC (polycarbonate)	63.2 g.	Data from manufacturer 1.	Polycarbonate {GLO}
Bottom case: PC (polycarbonate)	59.8 g.	Data from manufacturer 1.	Polycarbonate {GLO}
Privacy shield 1: PC (polycarbonate)	5 g.	Data from manufacturer 1.	Polycarbonate {GLO}
Privacy shield 2: Santoprene (assumed to mainly consist of polypropylene)	5 g.	Data from manufacturer 1.	Polypropylene, granulate {GLO}
Plastic frame: polyone (polyamide compound filled with 30 wt. % glass fiber)	4.15 g.	Data from manufacturer 1.	Glass fibre reinforced plastic, polyamide, injection moulded {GLO}
Contact plate: PC (polycarbonate)	0.55 g.	Data from manufacturer 1.	Polycarbonate {GLO}
Holder: PC (polycarbonate)	3.51 g.	Data from manufacturer 1.	Polycarbonate {GLO}
SAM door: PC (polycarbonate)	10.3 g.	Data from manufacturer 1.	Polycarbonate {GLO}
Keypad: PC (polycarbonate)	9.7 g.	Data from manufacturer 1.	Polycarbonate {GLO}
Keypad: Silicon	21.98 g.	Data from manufacturer 1.	Silicone product {RER}| production
Liquid crystal display (+/-5*5*0.3 cm.)	10 g.	Model Datasheet	Liquid crystal display, minor components, auxilliaries and assembly effort {GLO; Glass, for liquid crystal display {GLO}| Backlight, for liquid crystal display {GLO}|
Copper wire	10 g.	Estimation	Copper, cathode {GLO}|
Printed circuit boards	30 g.	Model Datasheet and ‘weight calculation PCB’[7]	Printed wiring board, mounted mainboard, desktop computer, Pb free
Samsung s3c2410al-20 (CPU, +/-10*10mm)	0.5 g.	Model teardown and ‘product information S3C2410AL-20’[8]	Integrated circuit, logic type {GLO}|
Cy62177dv30II (SRAM, +/- 3*3mm)	0.03 g.	Model teardown and ‘datasheet CY62167EV30’ [9]	Integrated circuit, memory type {GLO}|
Mrd531b Triple Channel F2F Decoder IC (decoder, +/-5*5mm)	0.1 g.	Model teardown and estimation	Integrated circuit, logic type {GLO}|
8007b_c3 Double multiprotocol IC card interface (IC communication, 3*3mm)	0.03 g.	Model teardown and estimation	Integrated circuit, logic type {GLO}|
TDA8020HL Dual IC card interface (IC communication, 5*5mm)	0.774 g.	Model teardown and ‘mouser electronics TDA’[10]	Integrated circuit, logic type {GLO}|
AX88772 USB2.0 Fast Ethernet Controller 10*10mm)	0.5 g.	Model teardown and ‘mouser electronics TUSB’[11]	Integrated circuit, logic type {GLO}|
TUSB2046B 4 Port USB Hub (6*6mm)	0.174 g.	Model teardown and estimation	Integrated circuit, logic type {GLO}|
Verifone 08233-01-r (7*12mm)	0.5 g.	Model teardown and estimation	Integrated circuit, logic type {GLO}|
Paper roll	58 g.	Paper roll[12]	Paper, woodfree, coated {RER}

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[7] http://www.leiton.de/leiton-tools-weight-calculation.html

[8] http://us.100y.com.tw/chanpin.asp?mno=58182

[9] http://www.farnell.com/datasheets/109202.pdf

[10] http://eu.mouser.com/ProductDetail/NXP-Semiconductors/TDA8020HL-C1118/?qs=LOCUfHb8d9si9rZHH7fVog%3d%3d

[11] http://nl.mouser.com/ProductDetail/Texas-Instruments/TUSB2046BVFR/?qs=6gY4t2uohMyMq%252b%252bjecEiPQ%3d%3d

[12] http://www.pandapaperroll.com/80-x-80mm-thermal-roll-gsm-length-weight/

Terminal distributors advise customers (i.e. retailers) to never disconnect a payment terminal from the power supply in order for its software to be updated frequently. For this reason, it is assumed that all payment terminals are switched on 24 hours per day. Each day, for 23.55 hours, the terminal is in standby mode and for 0.45 hours (27 minutes) it is processing transactions per day. Different phases such as reading the card, creating an authorization message, or individually printing each card require different peaks of energy. The average total energy use per transaction per terminal is 0.23 Wh. Per day per terminal this is 6.18 Wh, and for all terminals in the Netherlands in 2015 this is ~702 MWh (including both payment terminals with and without printing functionality). Table 4 provides an overview of terminal energy use.

Table 4. Energy use of payment terminals, with and without a printing functionality*.

Step	Process	Energy State	U (V)	I (A)	P (W) (U*I)	Time (s) and in hours (h)	E (Wh) For one transaction	Total energy usage per day per terminal (E * 27 times)
1.	Standby mode	Suspended, backlight off	9.0	0.022	0.2 W	Rest of the day (23.55h)	0.1744 Wh	4.7100 Wh
2	Merchant enters amount	Idle, backlight on	9.0	0.170	1.53 W	6 sec (0.00168 hour)	0.0026 Wh	0.0694 Wh
3	Display: your card please (no card present yet)	Backlight on, NFC reader on	9.0	0.382	3.438 W	6 sec (0.00168 hour)	0.0058 Wh	0.1559 Wh
4	NFC Transaction	Peak current	9.0	0.414	3.726 W	6 sec (0.00168 hour)	0.0063 Wh Total: 1 min	0.1690 Wh
5	Printing*	Peak current	9.0	n/a	30 W	3 sec (0 sec*) (0.0008 hour)	0.0240 Wh	0.6480 Wh
6	Other: time to go into standby mode again, etc.	Idle, backlight on	9.0	0.170	1.53 W	39 sec (42 sec)* (0.0104 hour) (0.012 hour)*	0.0159 Wh 0.0184 Wh*	0.4300 Wh 0.4967 Wh*
	Total energy use						0.23 Wh	6.18 Wh
	Total energy use*						0.21 Wh*	5.60 Wh*
	Total energy usage all terminals with printing facility in the Netherlands in 2015						356.8 MWh	
	Total energy usage all terminals without printing facility in the Netherlands in 2015						345.1 MWh	

* Energy use for payment terminals without a printing facility

One of the main goals of recycling companies is to put products, both for economic as well as environmental reasons, back on the market as much as possible. Based on an interview with an electronic waste recycling company, it is assumed that the lifetime of the average payment terminal –

which is 5 years – is three times greater to account for re-use. Processing plants are able to recover the terminals' materials before or after incineration through metal recovery from MWI bottom ash, after which the material is recycled and used again. However, this will only occur when no re-use options are available. Recycling as a disposal method is modelled via a calculation made with regard to the reuse potential of terminal (parts). This is elaborated on in section 3.1. The calculated potential energy recovery potential of the polycarbonate casing per terminal after incineration is 1.651 MJ.[13] Moreover, other components such as electronic parts are modelled via specific treatment indicators within SimaPro (Table A.3.). When not incinerated, 1-2% is modelled as landfill (Personal interview, payment terminal producer, 2016).

Figure 3 gives a schematic overview of the boundaries of the payment terminal system. The boundaries are mainly related to parts of the transportation and the disposal phase. Whenever possible, approximations have been made when primary data were unavailable. Transport in the Netherlands includes the transportation of the payment terminals from the port of Rotterdam to a single distribution centre, and from this distribution centre to the customers, i.e. the retailers that accept debit card payments. Additionally, at the end of the life cycle, the transport of the payment terminals from the customers back to the distribution centre and to the recycling facility is estimated. Similarly to debit cards, the transportation of raw materials for the production of payment terminals to production facilities in South-East Asia and the transportation of the payment terminals from the production facilities to the ports of China and Malaysia are not taken into account. This is because there is no information available about the production facilities and location from which the raw materials are retrieved. Overall, we expect the impact of these exclusions on the estimated environmental pressure of payment terminals to be limited. Table A.2 in the appendix lists information on transportation numbers.

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[13] According to Endres & Siebert-Raths (2009) both the electronic and gas incineration of the polycarbonate casing of a terminal amounts 30 MJ/kg. According to CE Delft the efficiency of electronic incineration amounts 17% and of gas incineration 19%. As a terminal contains 0.152 kg on polycarbonate, the energy generated through electronic incineration amounts 0.775 MJ and through gas incineration 0.866 MJ, leading to a total energy recovery of 1.641 MJ.

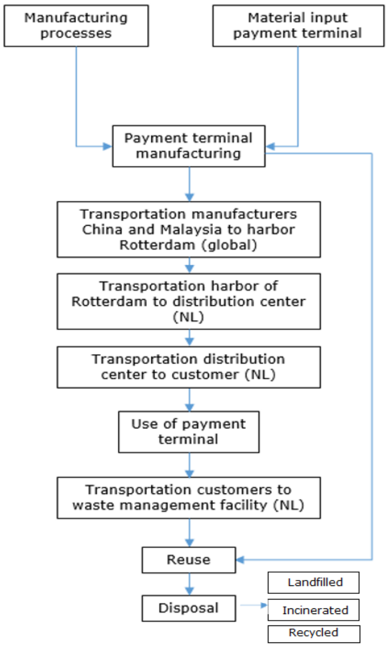

Figure 3. Schematic overview of the payment

Four primary manufacturing processes are studied: the assembly of the liquid crystal display, injection moulding, metalworking and mounting. A detailed overview of the material input of payment terminals is prepared using web-based references and information from terminal manufacturers.

The disposal phase is difficult to model, as detailed information on the recycling or reuse processes and the treatment routes is generally scarce (Fakhredin et al., 2013). Based on an interview with a processor of electronic waste, it is assumed that terminals are processed according to WEEELABEX standards, as drafted by the European Association of Electrical and Electronic Waste Take Back Systems. Therefore, all terminal components are assigned waste treatment processes in the SimaPro model. Though the shipment of hazardous wastes from the EU to non-OECD countries has been illegal for more than two decades, it is estimated that around 8 million tons of e-waste are imported illegally from the EU into China every year (Geeraerts et al., 2015). In addition, it is sometimes uncertain whether functioning electronic devices, which are considered non-usable in the Netherlands, are exported to countries where they will be re-used (Williams et al., 2013; Franquesa et al., 2015). Although it is likely this happens, the scale at which terminals, or terminal components, are transported to other countries after replacement of their secure components is unknown. Therefore, sensitivity analyses using re-use factors of 1, 2, and 4 lifetimes are used in order to draw conclusions on the impact of this more or less unknown end-of-life scenario of terminals. It is assumed that, also after this extended lifetime, payment terminals are processed according to the Dutch disposal methods, i.e. confidential incineration and landfilling by certified processing plants, as described in this paragraph. The overall result in terms of environmental impact in the disposal phase might therefore be different because the terminals disposed in other countries are not disposed in similar ways and ratios.

2.2.3 Datacentres

Datacentres process electronic payment transactions. Processing takes place in two steps: the authorization step and the payment/clearing and settlement step. For the input of materials for datacentres, information was used from Oliveira (2012) and Whitehead et al. (2012). Oliviera provided an inventory for one cube within a datacentre, in which the focus was the following four components: chillers, pump racks, computer components and infrastructural components. These components are converted to input data consisting of kilograms of copper, steel, aluminium, lead, glass wool and chromium. The largest raw material contributors for these components are copper (44.3%), steel (15.2%), chromium steel (13.5%) and aluminium (9.5%). Next to these four components, the material input for IT equipment and power equipment have been taken into account in this study, using information on datacentre components from Whitehead et al. (2012). Table 5 provides a list of all components considered in this inventory, together with their estimated lifetimes (Green Grid, 2012). The EcoInvent V3.0 database is used to model the components and, similarly to payment terminals, the lifetime of IT-equipment components is extended due to reuse. The reuse factor applied to the servers within a datacenter is set at three times.

Regarding the energy use of datacentres, the environmental impact and the GWP is caused by both (1) the quantity of energy being consumed – which is intrinsically linked to datacentre efficiency– and (2) the type of energy being consumed – i.e. renewable vs. non-renewable energy (Whitehead et al., 2015). For an accurate estimation of the quantity and type of energy consumed by datacentres, information was retrieved from two datacentres and two banks, which cover a large part of the Dutch

Table 5. Datacentre materials and their expected lifetimes

Component	**Expected life time in years**
IT Equipment	
High-end servers	5-8
Storage	3-5
Network equipment (switches)	3-5
PCs/laptops	3-5
Power equipment	
Switch gear	20
Generators	20
PDUs	20
UPS	20
Batteries	3-5
Cooling equipment	
Chiller	20
Pumps	20
Building structure	
Building	20

Sources: Oliveira (2012), Green Grid (2012).

debit card market in the Netherlands, by means of interviews and data requests. Subsequently, the data have been extrapolated to the total subsector within the transaction processing chain, using market shares. Acceptant payment service providers (APSPs) require less than 5% of the total computing power, since their only function is to 'forward' the transaction. The subsector of the acquiring host providers (AHPs) consumes significantly more energy: almost 25 times as much as APSPs, and approximately three times the amount of acquiring banks. Table 6 shows the input values of the model, including the energy type. The type of electricity within the transaction processing sector has an approximate 2:1 ratio for non-renewable energy vs. renewable energy. This is around 5 times higher than the distribution within the average Dutch energy mix, which was 5.5% by the end of 2014 (CE Delft, 2016). For the modelling of the 'non-renewable' (standard) Dutch electricity mix, the process Electricity, low voltage {NO}| market for | Alloc Rec, S was used. The renewable electricity mix was based on Afman and Wielders (2014) and contains a 40% share of electricity from wind power, a 22.5% share of electricity from wood and a 37.5% share of electricity from biogas.

Table 6. Electricity consumption by different organizations and the accompanying datacentres in NL

Ecoinvent process	Total Amount (kWh per year)
[Non-renewable] energy mix NL	2 142 306 kWh
Renewable energy mix NL	916 060 kWh
Onshore wind energy NL	340 760 kWh
Hydropower NL	81 994 kWh

Sources: classified

An overview of the boundaries of the subsystem ‘datacentre’ is given in Figure 4. Datacentres are high-energy consumers, and historical assessment of their environmental impact and GWP has focused largely on energy consumption (Whitehead et al., 2015). This is mainly due to the (physical) complexity of datacentres. The facilities and IT equipment used in these centres are individually highly complex systems, with many parts manufactured by a large number of entities (The Green Grid, 2012). It is therefore difficult to estimate the environmental impact of the transportation of datacentre components to the production facilities. A distinction is made between materials modelled as ‘raw materials’, such as steel and copper used for the datacentre racks, and those modelled as ‘other’, such as components like the chillers and pumps. The latter can be modelled as a product using the Ecoinvent V3.0 database. In this study, we estimate the environmental impact of transportation using information from a previously conducted LCA on datacentres by Olivera (2012). For the input of materials, a number of major components of an average datacentre were taken into account, also based on Oliveira (2012): infrastructural components, chillers, pump racks and computers. These components were converted to input data for raw materials like copper, steel, aluminium, lead, glass wool, and chromium. Additionally, materials for power and IT equipment were added to complete this inventory based on Whitehead et al. (2012).

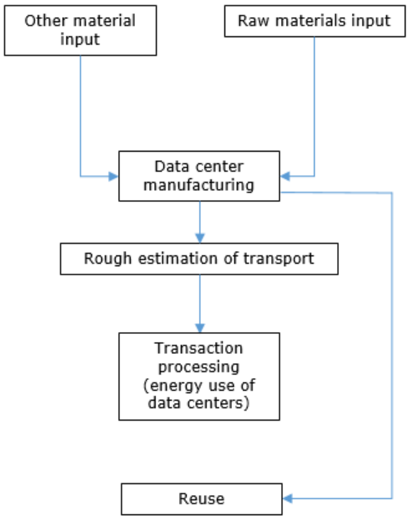

Figure 4. Schematic overview of a datacentre

For the energy use of transaction processing, the authorization and clearing processes are taken into account. The following payment service providers are involved with these processes: issuing banks which confirm payments and reserve/debit the authorized amount on the payer’s account: AHPs which are responsible for the actual processing of debit card transactions and which ‘route’ the authorization information of the payer to the appropriate issuing bank; and APSPs, which act as an intermediary between acquiring banks and merchants, by handling card payments on behalf of the merchants at their own account and risk. The energy consumption of the abovementioned service providers was estimated or retrieved by means of interviews.

The disposal inventory has not been extensively modelled. In this study, only a rough estimation was made of the components and respective weights present in an average datacentre, based on secondary information from Oliveira (2012) and Green Grid (2012). While this was not a complete overview of all materials in datacentres, the first results showed that the overall impact of datacentre materials was only 0.0001% of the total environmental impact of the debit card system. Although this initial result was not modelled extensively, we considered the relatively low impact enough reason to *not* create a fully complete, in-depth inventory of datacentre components, including their disposal methods. Assumed lifetimes of different components were retrieved from the literature such as Oliveira (2012), and Whitehead et al. (2012), but no re-use factors were applied.

3. Results

3.1 Main results

The environmental impact of one debit card transaction is calculated using the ReCiPe (H) Endpoint method, and results in 470 µPt. A way to make this number more tangible is to express the overall result also into one of its midpoint indicators, i.e. climate change impact. Using the IPCC GWP method, the calculated climate change impact per debit card transaction is 3.78 grams of CO_2-equivalents. This is equal to the impact of leaving on a 8W low-energy light bulb for one and a half hour, taking all processes into account which influence the environmental burden.[14] The environmental impact and the GWP of all debit card payments together in 2015 amount to approximately 1.5 million Pt and 12.2 million kg of CO_2-equivalents emitted according to IPCC GWP method. The latter figure indicates that the GWP of the debit card payment system corresponds to 0.006 percent of total CO_2 emissions in the Netherlands in 2015.

The share of each impact category is shown in figure 5. This analysis is also conducted using the ReCiPe Endpoint method, where 100% represents the previous result of 470 µPt per debit card transaction. The impact category that has the largest contribution to the total impact is fossil depletion (36%). This is mainly caused by the non-renewable energy used throughout the debit card payment system, of which the largest contribution is delivered by terminal energy use. Climate change human health, human toxicity and metal depletion contribute almost equally to the total impact, i.e. by 20%, 18% and 17% respectively.

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[14] The total environmental impact of 40 000 µPt is equivalent to the total environmental impact of 1 KWh of average Dutch electricity mix from 2013, according to CE Generic data in Simapro. So 470 µPt is equivalent to 11,75 Wh, or leaving on a 8 Wh saving light bulb for 1.5 hours (11 Wh/8W* 1 hour). Note that the total environmental impact is a broad concept including but not limited to energy usage. For instance, it also includes the impact of extracting resources on the environment, like metal depletion for manufacturing debit cards and terminals.

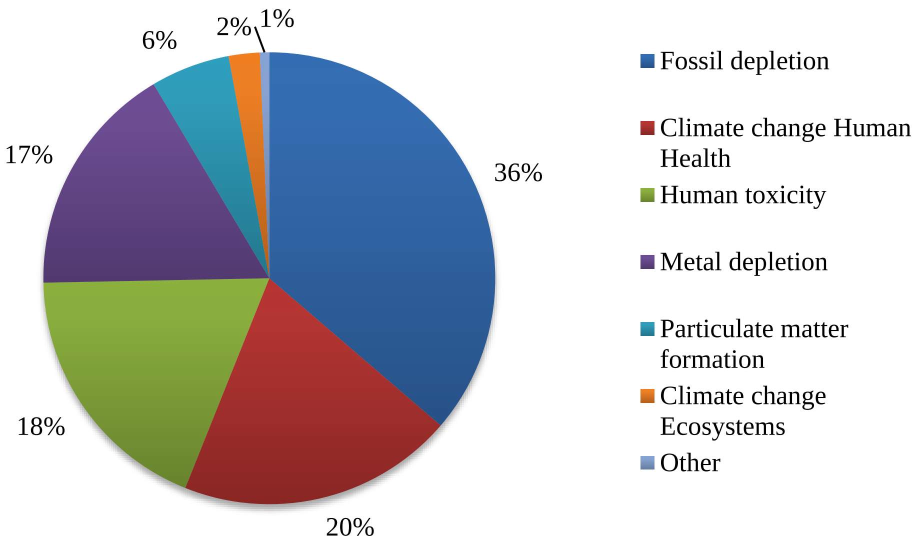


Figure 5. Relative contributions of impact categories to the total environmental impact of one debit card transaction, using the ReCiPe Endpoint method.

Figure 6 shows the environmental impact of the different subsystems, and their most important processes. The subsystem 'payment terminals' contributes the most to the environmental impact, i.e. 75%. Note that this is the outcome of the total environmental impact in Pt, and should not be confused with the GWP. The large impact of payment terminals is related to the relatively low number of daily debit card transactions per terminal per day: 27. This causes both the materials pressure – as well as the energy use – per transaction to be high. Datacentres are, in this respect, more efficient, as they process a much larger number of transactions on a daily basis. Their share in the total environmental impact is 11%. The share of the debit card in the total environmental impact of a debit card transaction amounts to 15%. Although the average number of transactions per debit card per day is small, i.e. 0.34, the share of the debit card on the total environment impact is moderate, due to the low material weight of the debit card. The low weight 'compensates' for the low number of transactions per card. Lastly, transportation within the Netherlands is modelled as Transport Terminal NL2 and NL3, respectively representing the transportation from the distribution centre to the customer and the transportation from the customer to the recycling facility. Both account for 4% of the environmental impact of a debit card transaction. Processes that are not visible include waste treatment of the battery

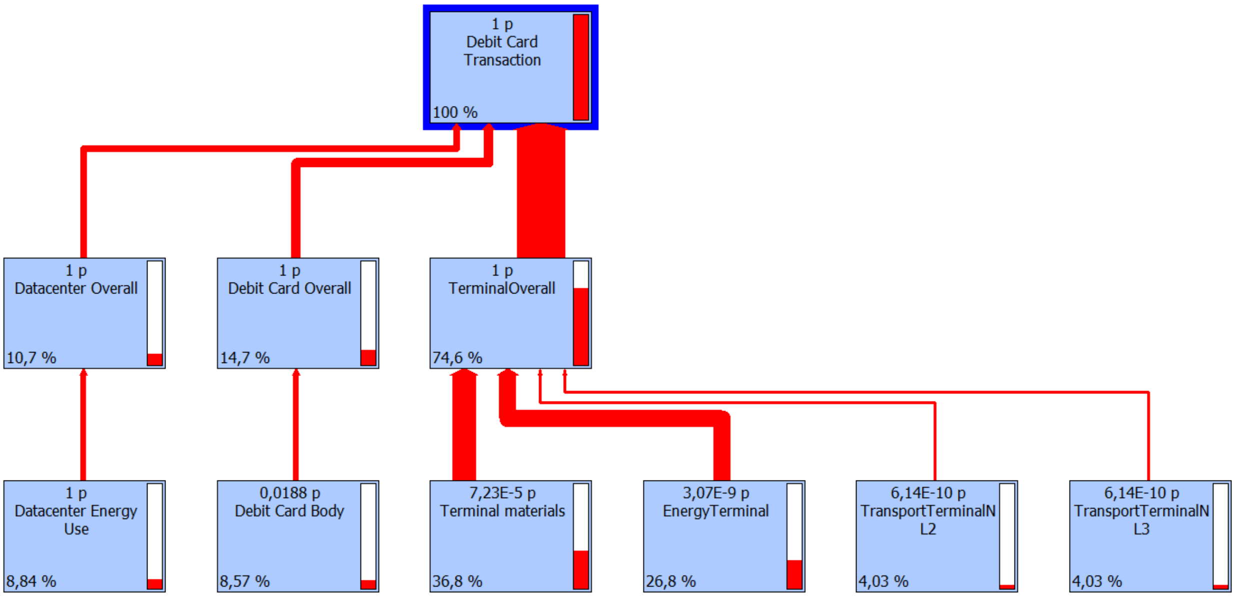


Figure 6. Overall result debit card transaction system. Cut-off: 4%. Processes that individually account for less than 4% are not shown.

of a terminal (0.2%), and treatment of other WEEE (0.4%). The incineration of debit cards generates a *negative* environmental impact of -2%, thereby decreasing the total environmental impact. In order to assess the underlying processes behind the overall environmental impact, a closer analysis –on process level– is performed. Figure 7 presents the results of this analysis. This figure highlights the areas of environmental importance within the debit card payment chain, indicating areas that might be of interest for policy makers to tackle. By categorizing processes according to their origin, the largest contributors on process level on average per transaction are shown to be two terminal material components taken together (31%): the printed wiring board (21%), and the logic processing chips (10%). This is followed by the non-renewable energy that is used by payment card terminals (27%), and the environmental impact of the transportation of payment card terminals (8%).

Note that the impact of the terminal materials has some uncertainties, such as disposal methods. However, the magnitude of its estimated environmental impact suggests that even when using different assumptions regarding the disposal method, terminal materials would still be one of the most important

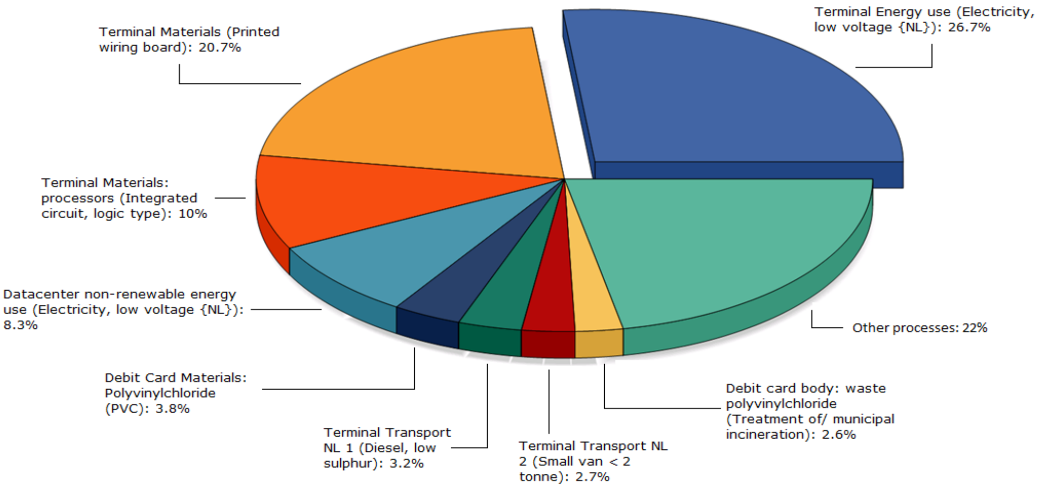


Figure 7. Single score analysis debit card transaction: process level using the ReCiPe (H) Endpoint v.12 method in Simapro

factors of the environmental burden of a debit card payment. Terminal energy use has a major environmental impact due to its non-renewable character, and because of the relatively modest number of debit card transactions per day (one transaction every 53 minutes). Furthermore, the datacentre energy use – which is partially non-renewable – shows a significant environmental impact (8%). Although it is estimated that almost one-third of all energy that is consumed by datacentres involved with processing debit card transactions is already renewable, increasing the share of renewable energy is possible. The debit card’s body, made mostly out of PVC, has an environmental impact of 6%: half of this results from its production and half from its municipal waste disposal. Other processes, such as transport, renewable energy consumption, or other materials account for the remaining 22%, as each individually accounts for less than 2.5% they are not shown in Figure 7.

3.2 Scenario and sensitivity analysis

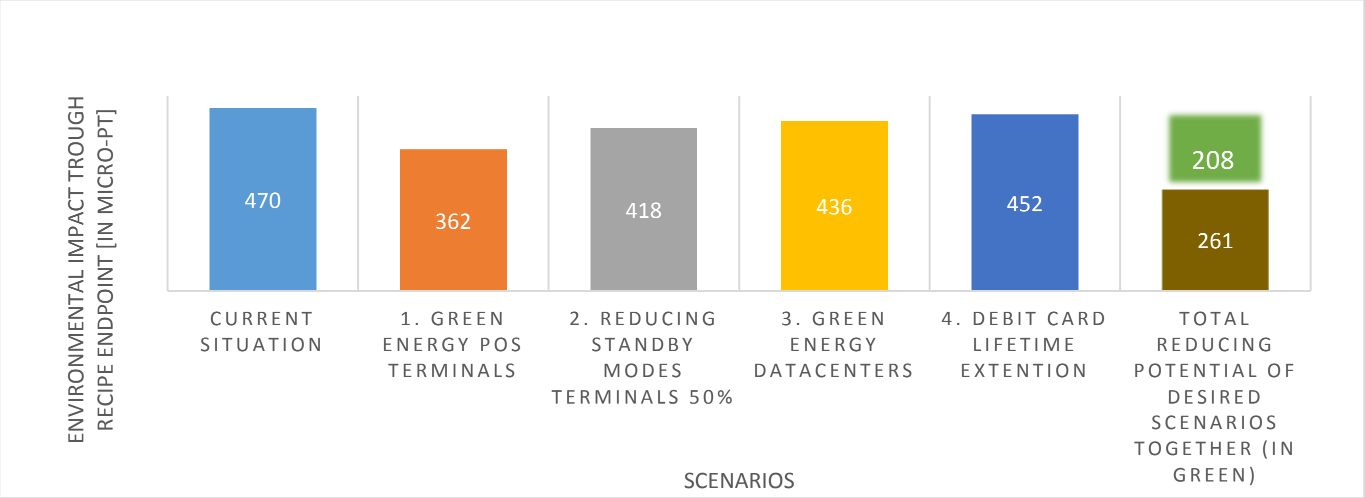
3.2.1 Scenario analysis

As stated by Fukushima and Hirao (2002): “it is common to have numerous alternatives and conditions that remain uncertain. (…) These can then be introduced into analysis when building strategies as a form of scenario for decision-makers." Therefore, after the process-level analysis of this research, possibilities of potential system changes that result in sizable impact changes have been evaluated. In order to do so, four scenarios are formulated, which have been constructed from the environmental hotspots as identified previously (Polizzi di Sorrentino et al., 2016).

1. All POS payment terminals in the Netherlands use renewable energy.
2. All POS payment terminals in the Netherlands reduce their standby modes by 50%.
3. All datacentres involved with transaction processing use renewable energy.
4. The lifetime of debit cards is increased to 5 years (instead of 3.5).

These scenarios are considered reasonably realistic, in terms of investment costs for stakeholders in the debit card chain. Methods such as repurposing products for use may have larger decreasing impacts on the functional unit, yet involve thorough analysis with greater uncertainties (Zink et al., 2014). Furthermore, the selected scenarios are in line with the Dutch government's aim to increase the use of renewable energy from 5% (current situation) to 14% in 2020 and 100% in 2050 (SER, 2013; Dicou et al., 2016). Figure 8 shows the average environmental impact of a debit card transaction in the current situation, compared to the four scenarios and for all four scenarios jointly. In scenario 1 the total environmental impact of a debit card payment is reduced by 23% compared to the current situation. This impact is substantial, which indicates that policies aimed at stimulating the use of renewable energy have the potential to lower the environmental impact of a product system considerably. A lesser, yet noticeable impact of 7% can be observed for scenario 3 in which all datacentres consume renewable energy. One of the reasons why scenario 3 has a smaller impact than scenario 1 is that approximately one third of all datacentres which process debit card payment transactions already use renewable energy sources, whereas only 6% of the POS payment terminals use renewable energy. Reducing the time that terminals are on standby mode by 50% (scenario 2) decreases the environmental footprint of a debit card transaction by 11%. Setting fixed times at which terminal providers update their terminals with new software might help in reducing the energy use of POS payment terminals. Retailers can then turn off their terminals when their store is closed, instead of keeping them switched on 24 hours a day. In scenario 4, the lifetime of a debit card is extended by 1.5 years to 5 years. The introduction of contactless payments with the debit card in the Netherlands may indeed increase the lifetime of debit cards, as holding the debit card against the payment terminal instead of inserting it into the terminal can lead to less material abrasion of the debit card´s body. Extending the lifetime results in a reduction of the overall environmental impact of a debit card transaction by 4%. In the overall scenario, which includes the features of all four scenarios, the environmental impact of a debit card transaction is reduced by 44%. The overall scenario has been included to put into perspective the potential steps that can be made in 'greening' the debit card payment system.

Figure 8. Scenario Analysis of four process changes within the debit card payment system



3.3.2 *Sensitivity analysis*

An accurate assessment of the end-of-life phase of payment terminals was not possible due to the lack of data. Therefore, sensitivity analysis have been performed in order to establish the influence of alternative lifetimes for POS payment terminals on the environmental impact of a debit card payment. The 'current situation' scenario describes a total average lifecycle of all materials for 15 years, based on a lifetime of 5 years for a payment terminal in the Netherlands and two recycled lifetimes for terminals or as terminal components in other countries. This implies that terminals or terminal components will be shipped overseas after usage in the Netherlands, and re-used in other countries after secured processing. In the sensitivity analysis, three alternative re-use factors have been used for a POS payment terminal, i.e. 0 (no re-use), 1 and 3. If a terminal were directly disposed of and incinerated after five years in the Netherlands, the environmental impact of a debit card transaction would be 813 µPt instead of 470 µPt, an increase of 73%. If the POS terminal, or its components were re-used once instead of twice, the environmental impact of a debit card transaction would rise by 18 % to 555 µPt. However, when assuming that terminals or their components would last five years longer than the assumed 15 years, the environmental impact of a debit card transaction would decrease with 9% to 426 µPt. The sensitivity analysis shows that the overall impact of a debit card transaction is sensitive to variations in the assumed lifetime of payment terminals and their materials.

4. Discussion

4.1 Putting the environmental pressure of the debit card payment system into perspective

The total number of debit card transactions in the Netherlands in 2015 results in an environmental burden of approximately 1.5 million Pt and has a GWP of approximately 12.2 million kg CO_2-equivalents, which corresponds to 0.006% of the GWP of the Netherlands in 2015 (CBS, 2016).[15] In order to compare the debit card payment system and the Dutch economy as a whole, while taking into account their differences in economic value, their GWPs were scaled. The economic value associated with the debit card payment system was proxied by its resource costs, which was approximately EUR 863 million in 2015.[16] The economic value of the goods and services produced in the Dutch economy was approximated by the value of the gross domestic product of the Dutch economy in 2015, which was EUR 676.5 billion (CBS, 2016b). A comparison of the debit card system's GWP with the GWP of the Dutch economy as a whole relative to their economic values, suggests that the impact of the debit card payment system on climate change is relatively modest (Table 7). Per EUR billion economic value the GWP of the debit card system is 20 times smaller than the average GWP of all goods and services in the Dutch economy in 2015.

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[15] As the total environmental impact of the Dutch economy is unknown, but its GWP is known, the GWP of the debit card system is compared with the GWP of the Dutch economy.

[16] The economic importance of the of debit card payments in 2015 was proxied by their resource costs to society. Resource costs for debit card payments refer to the costs to society (i.e. banks, retailers, datacentres and clearing houses) reflecting the use of resources in the production of debit card payments. Cost figures for the year 2009 (Jonker, 2013) have been extrapolated taking into account the share of the costs which vary with debit card usage, the growth in debit card usage between 2009 and 2015 and the development of the prices in the services sector.

Table 7. Global warming potential debit card system relative to the Dutch economy, 2015

	CO2-equivalents (in kg CO2)	Economic value (in EUR billion)	GWP – economic value ratio (kg CO2-eq. per EUR billion)
Debit card	$122*10^5$	0.9	$14*10^6$
Dutch economy	$196*10^9$	676.5	$287*10^6$

Note: GWP potential and GDP of the Dutch economy in 2015 are from CBS (2016a, 2016b)

Also a comparison with the total environmental impact and the GWP of the cash payment system in the Netherlands in 2015 puts those of the debit card system into perspective. Hanegraaf (2017) and Larcin (2017) analyse the environmental impact of an average cash payment in the Netherlands in 2015. It turns out that the total environmental impact of an average cash payments amounts 700 µPt and has a GWP of 5.0 gram CO2-equivalents. These results indicate that the total environmental impact of a cash payment is 1.5 times higher and that its GWP is 1.3 times higher than of a debit card payment. The relatively higher impact of cash on the environment as a whole than on climate stems among others from the fact that the metal depletion for coin production affects the environment, but not climate. The somewhat higher environmental impact of cash payments on the environment as a whole and on climate compared to debit card payments suggests that the substitution of cash by debit card payments, which takes place in many countries, may enhance the sustainability of the POS payment system.

5. Conclusions and limitations

In this study, the environmental impact of a debit card payment in the Netherlands in 2015 is evaluated using life cycle assessment. For each subsystem in the debit card payment chain (debit card, payment terminals and datacentre) an inventory was created of all data collected during interviews and from the literature.

The outcome for the environmental impact of one debit card transaction is measured through the ReCiPe (H) Endpoint method, resulting in 470 µPt. The environmental impact of all debit card payments together amounted to 1.5 million Pt and has a GWP of 12.2 million kg CO_2 equivalents, which corresponds with 0.006% of the total GWP of the Netherlands in 2015 (CBS, 2016).

At roughly 75%, POS terminals take up the largest share of a debit card payment's total environmental impact, mainly due to their materials (37%), represented largely by the printed wiring board, and integrated circuit, and energy consumption (27%). The contribution of the debit card to the environmental impact is 15%, with the base materials needed to produce them, specifically PVC, being the key components. The processing of a debit card payment by a datacentre accounts for around 11% of the total environmental impact. Its principal component is energy consumption.

Four scenarios, in which all datacentres and terminals use renewable energy, the standby time of terminals is halved, and the lifetime of debit cards is extended from 3.5 to 5 years, are evaluated. Combining them shows one of the main conclusion of this research, which is a potential reduction in total environmental pressure of a debit card transaction by 44%. A comparison of the environmental impact and GWP of debit card payments with cash payments suggests that the ongoing substitution of cash by card payments by consumers may enhance the sustainability of the POS payment system.

Since this is the first study in this area, it is important that further research is conducted to strengthen the results. The main limitations of this report relate to the scarcity of data mainly present in the end-of-life phase of payment terminals. This is a complex issue, which should be evaluated in more detail in further studies. Results might alter if such phases are modelled more thoroughly. Also, many data are extrapolated to the entire system of debit card payments, while only data from one source was consulted. Inventory data could be made more robust in further research, by expanding the number of references. This holds mainly for debit card manufacturing, datacentre energy use, transportation and payment terminals. Also, the postal industry necessary for the postal delivery of cards to users and telecommunication infrastructure necessary to transmit information between the actors in the debit card payment system could be included in the scope of follow-up studies. Furthermore, studies that evaluate the environmental impact of other electronic payment instruments than debit card will provide more context to this study's results.

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Appendix

Table A.1. Inventory of European transportation of debit cards.

Transport	Distance	Source
Driving distance from chip module production facilities (Southern France) to the card production and assembling facilities (Eastern Europe).	Minimum 1300 km from Southern Europe to Eastern Europe 1 Maximum: 1500 km from Southern Europe to Eastern Europe 1 Average: 1400 km	(Personal communication bank 1, 2016).
Driving distance from card production facilities (Eastern Europe) to the personalization facilities (the Netherlands)	Maximum: 1300 km from Eastern Europe 1 to NL 1 Minimum: 700 km from Eastern Europe 2 to NL 2 Average: 1000 km	(Personal communication bank 1, 2016).
Average driving distance from customer to municipal waste incinerator	30 km (14 municipal waste incinerators in the Netherlands, min 1 km, max. 60 km).	Own calculation
Number of orders per year	~10 times per year for all Dutch banks	(bank 1, 2016).
Number of cards transport per year	7.79 million	Own estimation based on information from bank 1 and Lievaart, 2011.
Transport EU per year (in tkm)	93 480 tkm (7.79 million cards * 2400 total km * 0.000005 tonnes (5g))	Own calculation
Type of transport	Truck, lorry 10-20t capacity	Ecoinvent 3.0

Table A.2. Transportation estimates terminals.

Transport	Type of Transport (As modelled in SimaPro)	Distance	Source
Distance from China (Shanghai) and Malaysia (Port Kelang) to the harbour of Rotterdam.	Transoceanic Freight Ship (RER)	Shanghai: 20,000 km Malaysia: 15,000 km Average: 17,500 km	Interview, Searates[17]
Distance Rotterdam to a terminal's distribution centre:	Truck (lorry 28t) (RER)	120 km	Interview
Transport for servicing terminals (global, yearly) in tkm	Small commercial vehicle (Van, <3.5t) (RER)	350000 tkm	Own calculation
Transport distribution centre to customer (NL, yearly) in km	Transport, Lorry 3.5-7.5t (RER)	2400 tkm	Own calculation
Transport from customers to terminal recycling centre	Transport, Lorry 3.5-7.5t (RER)	2400 tkm	Own calculation

Table A.3. Modelling the waste treatment of a terminal in Simapro

Indicator selected in SimaPro	Amount (gram)
Waste electric and electronic equipment {GLO}| treatment of, shredding | Alloc Rec, U TEST	200
Used Li-ion battery {GLO}| treatment of used Li-ion battery, hydrometallurgical treatment | Alloc Rec, S	30
Used liquid crystal display {GLO}| treatment of, mechanical treatment | Alloc Rec, S	2
Waste electric wiring {RoW}| treatment of, collection for final disposal | Alloc Rec, S	10
Waste electric and electronic equipment {GLO}| market for | Alloc Rec, S	50
PE (waste treatment) {GLO}| recycling of PE | Alloc Rec, U	0
Electronics scrap from control units {GLO}| market for | Alloc Rec, S	20
Waste polyethylene {RoW}| treatment of waste polyethylene, sanitary landfill | Alloc Rec, S	1

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